

# Absolute values of nonstandard interaction parameters in $\nu_e e$ and $\bar{\nu}_e e$ -scatterings.

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## Abstract

We present a novel approach for constraining nonstandard neutrino interaction (NSI) coupling parameters ( $\varepsilon_{ee}^{eL}$  and  $\varepsilon_{ee}^{eR}$ ) in low energy flavor conserving  $\nu_e e$  and  $\bar{\nu}_e e$ -scattering processes. Here we exploit an important phenomenon of interference and assuming that  $\varepsilon_{ee}^{eL}$  and  $\varepsilon_{ee}^{eR}$  are same for both the processes as  $g_L$  and  $g_R$  in the standard model (SM). Using this approach we obtain the absolute values  $\varepsilon_{ee}^{eL} = 8.7 \times 10^{-3}$  and  $\varepsilon_{ee}^{eR} = 3.8 \times 10^{-1}$ , while the bounds obtained using the said processes are  $-0.11 < \varepsilon_{ee}^{eL} < 0.13$  and  $0.35 < \varepsilon_{ee}^{eR} < 0.41$ . It is noteworthy that the lower bound on  $\varepsilon_{ee}^{eR}$  exclude the negative region. Furthermore, our bounds on  $\varepsilon_{ee}^{eR}$  are more stringent than the existing ones.

**Key words:** Neutrino mass, Nonstandard neutrino interactions, Interference effect, New physics.

## 1 Introduction

The discovery of neutrino masses in the neutrinos oscillation experiments necessitates the existence of new interactions called nonstandard neutrino interactions (NSI) [1, 2, 3, 4]. These new interactions along with the massive neutrinos are predicted by various models [5, 6], involving those where neutrinos acquire masses through see-saw mechanism [7, 8, 9, 10, 11], those where neutrinos gain masses radiatively due to the presence of extra Higgs bosons [12, 13, 14] and the R-parity violating supersymmetric models [15, 16, 17, 18, 19]. At low energy effective level the current structure of the NSI is similar to that of four Fermi interactions [20]. The NSI may be nonuniversal flavor- conserving or flavor-changing contrary to standard model (SM) currents which are universal and flavor conserving.

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The various methods to constrain the NSI coupling parameters at effective level are extensively studied in the literature [20, 21]. Here, we present a novel approach, not only constraining the NSI parameters, but also computing the absolute values of these parameters. In this approach, we take the low energy flavor conserving  $\nu_e e$  and  $\bar{\nu}_e e$ -scattering processes and calculate their total cross sections in terms of NSI coupling parameters ( $\varepsilon_{ee}^{eL}$  and  $\varepsilon_{ee}^{eR}$ ) which appear due to adding the effective four fermion operators for NSI to the electroweak Lagrangian. Analytically, both cross sections contain terms linear in  $\varepsilon_{ee}^{eL}$  and  $\varepsilon_{ee}^{eR}$ . These terms arise due to the interference effect between various currents (some are the SM ones and the others are due to NSI). These terms in turn lead to two equations linear in  $\varepsilon_{ee}^{eL}$  and  $\varepsilon_{ee}^{eR}$  for the corresponding processes. Solving the two linear equations simultaneously we obtain the absolute values of  $\varepsilon_{ee}^{eL}$  and  $\varepsilon_{ee}^{eR}$ .

We use the measured values of cross sections for  $\nu_e e$  and  $\bar{\nu}_e e$ -scattering processes of LSND and ROVNO experiments, respectively, evaluating the interferences in terms of  $\varepsilon_{ee}^{eL}$  and  $\varepsilon_{ee}^{eR}$  and then compare these with corresponding measured values (for detail see ref. [22]). Although the total cross section is directly proportional to the neutrinos energy, but the interference terms are independent of energy because we derive these by taking the ratios of the measured and predicted values of total cross sections. At first stage, we ignore the experimental errors and restrict ourselves to current discrepancy between theory and experiment for the two processes and obtain absolute values of  $\varepsilon_{ee}^{eL}$  and  $\varepsilon_{ee}^{eR}$ . At second stage, we incorporate the experimental errors and calculate the upper and lower bounds on  $\varepsilon_{ee}^{eL}$  and  $\varepsilon_{ee}^{eR}$ . The absolute values obtained lie within the range of these bounds.

Our analysis is based on two assumptions: (i) As in SM, where two coupling constants  $g_L$  and  $g_R$  are same both for  $\nu_e e$  and  $\bar{\nu}_e e$ -scattering processes, similarly NSI coupling parameters  $\varepsilon_{ee}^{eL}$  and  $\varepsilon_{ee}^{eR}$  are also assumed to be same for both the processes. (ii) We take only the flavor conserving  $\nu_e e$  and  $\bar{\nu}_e e$ -scattering processes and ignore the flavor violating processes. This is because the interference effect, which is core of our discussion, could only occur in the flavor conserving process (for detail see ref. [22]).

## 2 Lagrangian of NSI

The most general form of the effective four-fermion interaction Lagrangian for low energy ( $\nu_\alpha f \rightarrow \nu_\beta f$ ) process in the presence of NSI is given by [20],

$$\begin{aligned} \mathcal{L}_{eff} = & -2\sqrt{2}G_f[\bar{\nu}_\alpha\gamma_\mu L l_\alpha][\bar{f}\gamma^\mu P f'] - 2\sqrt{2}\sum_{p,f,\alpha} g_p^f G_f [\bar{\nu}_\alpha\gamma_\mu L \nu_\alpha][\bar{f}\gamma^\mu P f] \\ & - \sum_{\alpha,\beta} \epsilon_{\alpha\beta}^{fp} 2\sqrt{2}G_f[\bar{\nu}_\alpha\gamma_\mu L \nu_\beta][\bar{f}\gamma^\mu P f] \end{aligned} \quad (1)$$

where the first and second terms are the SM operators and the third one is the NSI four fermion operator,  $P = L, R = \frac{1}{2}(1 \mp \gamma_5)$  with  $G_F$  as the Fermi constant,

$f$  is any lepton or quark and  $f'$  is its SU(2) partner,  $g_p^f$  are the neutral current coupling constants in the SM and  $\epsilon_{\alpha\beta}^{fp}$  are the nonstandard flavor conserving ( $\alpha = \beta$ ) and flavor changing ( $\alpha \neq \beta$ ) effective coupling parameters.

Applying Fierz transformation, the total effective Lagrangian for the specific process of  $\nu_e e$ -scattering becomes,

$$\begin{aligned}\mathcal{L}^{eff} = & -2\sqrt{2}G_f[\bar{\nu}_e\gamma_\mu L\nu_e][\bar{e}\gamma^\mu Pe] - 2\sqrt{2}g_p^f G_f [\bar{\nu}_e\gamma_\mu L\nu_e][\bar{e}\gamma^\mu Pe] \\ & - \epsilon_{ee}^{ep} 2\sqrt{2}G_f[\bar{\nu}_e\gamma_\mu L\nu_e][\bar{e}\gamma^\mu Pe]\end{aligned}\quad (2)$$

### 3 Size of Interference in SM and in measurements

By taking the standard model part of Lagrangian in eq.(2), the total cross section of  $\nu_e e$ - scattering process can be calculated as,

$$\sigma^{\nu_e} = \sigma^o[(g_L + 2)^2 + \frac{g_R^2}{3}] \quad (3)$$

where  $\sigma^o = \frac{G_f^2 m_e E_{\nu_e}}{2\pi} = (4.31 \times 10^{-45}) cm^2 \times E_{\nu_e}(MeV)$ ,  $g_L = -1 + 2 \sin^2 \theta_w$  and  $g_R = 2 \sin^2 \theta_w$  or more explicitly

$$\sigma^{\nu_e} = \sigma^o[4 + (g_L^2 + \frac{g_R^2}{3}) + 2(I)] \quad (4)$$

in the third term,  $I = 2g_L$  is the interference between the charged and neutral currents of the SM. Assuming  $\sin^2 \theta_w = 0.23$ , we get  $g_L = -0.54$  and  $g_R = 0.46$ .

Substituting numerical values and including the radiative corrections [26, 27], we obtain,

$$\sigma^{\nu_e e} = 4\sigma^0 + 0.37\sigma^0 + 2(-1.09)\sigma^0$$

where the size and sign of interference in the SM is

$$I_{\nu_e e}^{SM} = -1.09 \quad (5)$$

From eq. (5), it is clear that the standard model predicts destructive interference (negative sign) between  $CC$  and  $NC$  having size 1.09. Using  $\sigma_{\text{exp}} = [10.1 \pm 1.1(stat.) \pm 1.0(syst.) \times E_{\nu_e}(MeV) \times 10^{-45} cm^2]$  in eq. (4) from the LSND experiment [26] and solving for  $I$ , we get  $I^{LSND} = -1.01 \pm 0.18$ . Comparing  $I^{SM}$  and  $I^{LSND}$ , one can see a discrepancy of 0.08. The destructive interference(-ev sign) is in agreement with, the theory and experiment.

The total scattering cross section for  $\bar{\nu}_e e$  can easily be obtained by interchanging  $g_L$  and  $g_R$  in eq. (3) as,

$$\sigma^{\bar{\nu}_e} = \sigma^o \left[ \frac{1}{3}(g_L + 2)^2 + g_R^2 \right] \quad (6)$$

more explicitly,

$$\sigma^{\bar{\nu}_e e} = \sigma^o \left[ \frac{4}{3} + \left( \frac{g_L^2}{3} + g_R^2 \right) + 2(I) \right] \quad (7)$$

where  $I = \frac{2}{3}g_L$  is interference between the charged and neutral currents of the SM. Substituting  $g_L = -0.54$  and  $g_R = 0.46$ , we obtain,

$$\sigma^{\bar{\nu}_e e} = 1.33\sigma^o + 0.31\sigma^o + 2(-0.36)\sigma^o$$

where we have calculated interference in the SM for  $\bar{\nu}_e e$ - scattering process as,

$$I_{\bar{\nu}_e e}^{SM} = -0.36 \quad (8)$$

It is clear from eq. (8) that SM predicts a destructive interference between  $CC$  and  $NC$  for the  $\bar{\nu}_e e$ - scattering process. When we calculate the size and sign of interference with the help of ROVNO data,  $[\sigma_{\text{exp}}^{\bar{\nu}_e e} = 1.26 \pm 0.62 \times 10^{-44} \text{cm}^2 \times E_{\nu_e}(\text{MeV})]$  [28], using the technique as adopted in [26], it comes out to be  $I^{ROVNO} = -0.18 \pm 0.072$ . Here the theory vs. experiment discrepancy is 0.18, which is much larger in comparison with  $\nu_e e$ - scattering process. This indicates that  $\bar{\nu}_e e$ - scattering process provides more room for new physics.

## 4 Absolute values of NSI coupling parameters $(\epsilon_{ee}^{eL}, \epsilon_{ee}^{eR})$

The total cross section of  $\nu_e e$ -scattering process in the presence of NSI, using the Lagrangian in eq. (4), can be calculated as

$$\begin{aligned} \sigma_{SM+NSI}^{\nu_e} &= \sigma^o \left[ (2 + g_L + \epsilon_{ee}^{eL})^2 + \frac{(g_R + \epsilon_{ee}^{eR})^2}{3} \right] \\ &= \sigma^o \left[ 4 + (g_L^2 + \frac{1}{3}g_R^2) + \{(\epsilon_{ee}^{eL})^2 + \frac{1}{3}(\epsilon_{ee}^{eR})^2\} \right. \\ &\quad \left. + 2\{2g_L + g_L(\epsilon_{ee}^{eL}) + 2(\epsilon_{ee}^{eL}) + \frac{1}{3}g_R(\epsilon_{ee}^{eR})\} \right] \end{aligned}$$

where the total interference is

$$I^{\nu_e} = \{2g_L + g_L(\epsilon_{ee}^{eL}) + 2(\epsilon_{ee}^{eL}) + \frac{1}{3}g_R(\epsilon_{ee}^{eR})\} \quad (9)$$

Similarly, for  $\bar{\nu}_e e$ -scattering process, the total cross section in the presence of NSI can be calculated as,

$$\begin{aligned} \sigma_{SM+NSI}^{\bar{\nu}_e e} &= \sigma^o \left[ \frac{4}{3} + \left( \frac{1}{3}g_L^2 + g_R^2 \right) + \left\{ \frac{1}{3}(\epsilon_{ee}^{eL})^2 + (\epsilon_{ee}^{eR})^2 \right\} \right. \\ &\quad \left. + 2\left\{ \frac{2}{3}g_L + \frac{1}{3}g_L(\epsilon_{ee}^{eL}) + \frac{2}{3}(\epsilon_{ee}^{eL}) + g_R(\epsilon_{ee}^{eR}) \right\} \right] \end{aligned}$$

where the total interference term is

$$I^{\bar{\nu}_e e} = \left\{ \left( \frac{2}{3}g_L + \frac{1}{3}g_L(\epsilon_{ee}^{eL}) + \frac{2}{3}(\epsilon_{ee}^{eL}) + g_R(\epsilon_{ee}^{eR}) \right) \right\} \quad (10)$$

Substituting  $g_L = -0.54$  and  $g_R = 0.46$  and comparing these with the corresponding measured values of interference we obtain

$$\{-1.08 + 1.46(\epsilon_{ee}^{eL}) + 0.15(\epsilon_{ee}^{eR})\} = I^{LSD} = -1.01 \pm 0.18 \quad (11)$$

and

$$\{-0.36 + 0.49(\epsilon_{ee}^{eL}) + 0.46(\epsilon_{ee}^{eR})\} = I^{ROVNO} = -0.18 \pm 0.072 \quad (12)$$

At first step, let us solve the two equations with respect to the central values of the two experiments and ignoring the experimental error so that obtain  $\epsilon_{ee}^{eL} = 0.0087$  and  $\epsilon_{ee}^{eR} = 0.3820$ .

By incorporating the experimental errors we obtain four equations corresponding to the upper and the lower limits of the experiments as

$$\begin{aligned} 1.46(\epsilon_{ee}^{eL}) + 0.15(\epsilon_{ee}^{eR}) &= 0.25 \\ 0.48(\epsilon_{ee}^{eL}) + 0.46(\epsilon_{ee}^{eR}) &= 0.252 \text{ (upper bound equations)} \end{aligned} \quad (13)$$

and

$$\begin{aligned} 1.46(\epsilon_{ee}^{eL}) + 0.15(\epsilon_{ee}^{eR}) &= -0.11 \\ 0.48(\epsilon_{ee}^{eL}) + 0.46(\epsilon_{ee}^{eR}) &= 0.108 \text{ (lower bound equations)} \end{aligned} \quad (14)$$

Simultaneous solutions of eqs. (13) and (15) give rise to the bounds,

$$\begin{aligned} -0.11 &< \epsilon_{ee}^{eL} < 0.13 \\ 0.35 &< \epsilon_{ee}^{eR} < 0.41 \end{aligned} \quad (15)$$

## 5 Conclusion

In this letter we have presented a new analysis for constraining the NSI coupling parameters ( $\epsilon_{ee}^{eL}$  and  $\epsilon_{ee}^{eR}$ ) exploiting an important phenomenon of interference between various currents in the elastic  $\nu_e e$  and  $\bar{\nu}_e e$ -scattering processes. Using this analysis, we obtained  $\epsilon_{ee}^{eL} = 8.7 \times 10^{-3}$  and  $\epsilon_{ee}^{eR} = 3.8 \times 10^{-1}$ . We also obtained the bounds:  $-0.11 < \epsilon_{ee}^{eL} < 0.13$ ,  $0.35 < \epsilon_{ee}^{eR} < 0.41$ . The absolute values are both positive and exclude the negative region while the bounds on  $\epsilon_{ee}^{eR}$  are more stringent and in particular it excludes the negative region.

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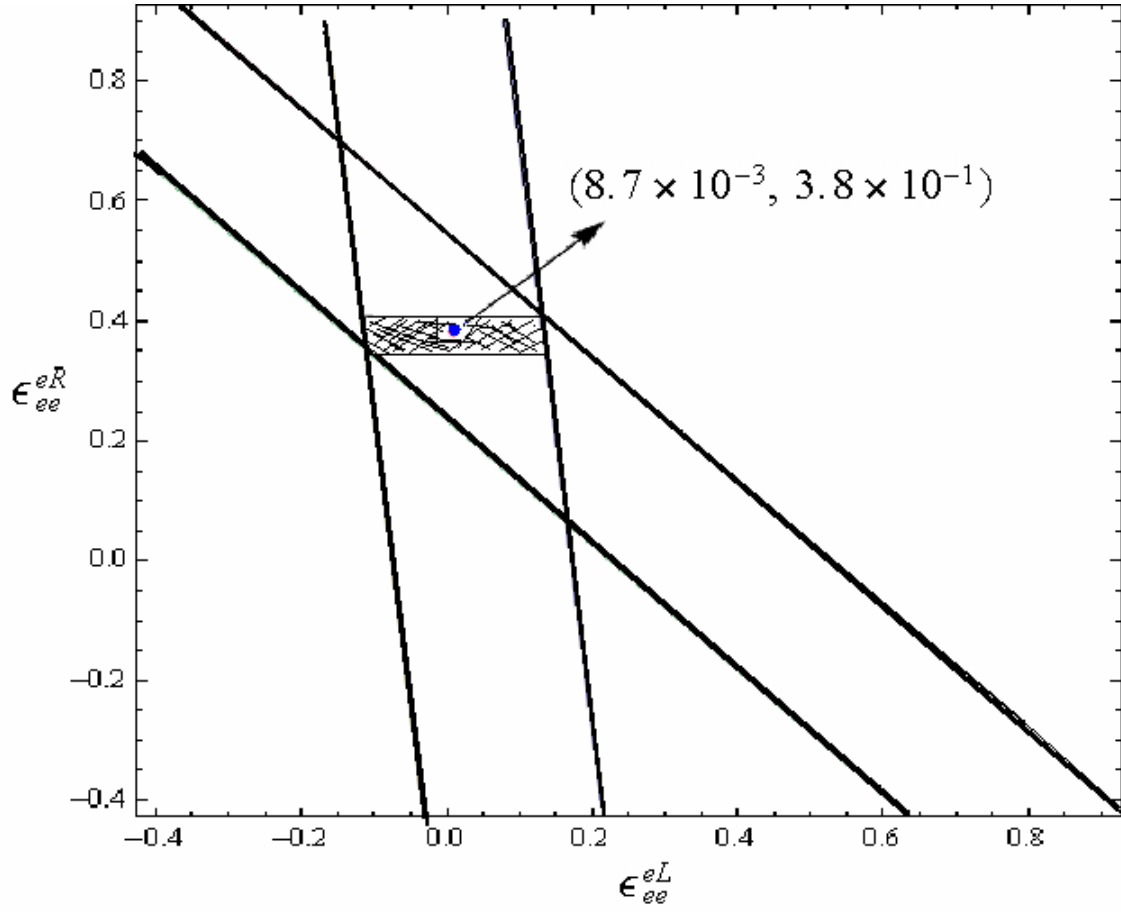


Figure: Contour plots of interferences ( $I^{\nu_e}$  and  $I^{\bar{\nu}_e}$ ) in terms of  $\epsilon_{ee}^{eL}$  and  $\epsilon_{ee}^{eR}$ . The shaded region corresponds to the bounds:  $(-0.11 < \epsilon_{ee}^{eL} < 0.13, 0.35 < \epsilon_{ee}^{eR} < 0.41)$  and the colored epi-point corresponds to the absolute values:  $(\epsilon_{ee}^{eL} = 0.0087, \epsilon_{ee}^{eR} = 0.3820)$ .